DRAFT REPORT

IN-DELTA STORAGE PROGRAM RISK ANALYSIS

Prepared for
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1.1 PURPOSE AND SCOPE

The Department of Water Resources (DWR) is conducting feasibility-level engineering and environmental studies under the Integrated Storage Investigations Program. As part of the project evaluations, DWR is evaluating the technical feasibility and conducting engineering investigation for the In-Delta Storage Program. The engineering investigation will aim at developing solutions to enhance project reliability through improved embankment design and consolidation of inlet and outlet structures.

As part of this feasibility study, DWR requested that URS Corporation (URS) undertake a detailed risk analysis and integrate the physical design with a desirable level of protection through seismic, flooding, operational, environmental, and economic analyses. Other objectives were to recommend a desirable of level of protection and an appropriate factor of safety for the project.

The specific scope of work under this task order was to evaluate the consequences of failure of the existing levees and In-Delta Re-engineered project (embankment and integrated facilities) under all loading events (operational, seismic, and flooding) and estimate the loss-of-life risk and economic losses through uncontrolled releases. The risk analysis was to be conducted in accordance with the general guidelines of the USBR risk analysis presented in a handout distributed during a scoping meeting on July 18, 2002 between DWR, USBR, and URS staff. These guidelines are also described in a U.S. Bureau of Reclamation document (USBR, 1999).

The main objective of this task order was to evaluate the risk of failure of the existing levees and In-Delta Re-engineered project for Webb Tract and Bacon Island. The results of the analysis were used to evaluate the expected project performance relative to the “no action” alternative (i.e., existing levee condition).

1.2 ASSUMPTIONS AND LIMITATIONS

The following is a list of assumptions and limitations used to evaluate probabilities and consequences of failure and to calculate the project risk:

- Probability of simultaneous occurrence of two major events (flooding and earthquake for this analysis) is negligible. This is a common assumption in risk analysis.
- The reservoir would operate at or near full level (elevation +4’) during the months of April through June and at or near empty level (elevation –15’) during the months of July through March.
- Probability of more than two simultaneous breaches of the embankment within each island due to flooding or earthquake is negligible.
- Probability of more than one simultaneous breach of the embankment within each island due to operational loading is negligible.
- Probability of failure of the levee on each neighboring island given that the embankment fails during flooding or earthquake is 100%. That is, if an earthquake or a flood causes the embankment to fail, it would also cause the levees on neighboring islands to fail. This is a reasonable assumption because the embankment would be an engineered project designed to

withstand the expected seismic and flooding loading. In contrast, most of the existing levees are not engineered structures and hence would be much more vulnerable to seismic and flooding events. Thus, if an earthquake or flood were strong enough to cause the engineered embankment to fail, it would cause the levees to fail as well.

- The simultaneous failure of the project embankment as well as the existing levees would cause system-wide hydraulic changes in the Delta. As stated above, if an earthquake or flood causes the failure of the embankment, it is also assumed to cause the failure of the levees on neighboring islands. In such a scenario, the overall impact of the system-wide hydraulic changes to water quality could be substantial. However, the incremental impact of the embankment failure to water quality by itself (for example, increased salinity) would not be significant. This is a reasonable assumption because the volume of water that would be drawn from the slough into the reservoir, or released from the reservoir into the slough, would be only a small portion of the total volume of water that would be drawn into all the other islands. Therefore, the impact to Delta water quality is analyzed only under an operational failure, but not under a failure due to flood or earthquake loading.
- Given a failure of the embankment due to operational loading and an outward breach that floods the slough, there is a finite probability that a levee on a neighboring island would fail due to flood wave impact. This probability of levee failure depends on the slough width (with higher probabilities for narrower sloughs) and also on the probability of successful flood fighting measures on the neighboring islands.
- During a flooding event, relatively little boating activity is assumed to be present in the slough.
- Only direct costs and benefits are included in the economic analysis. Indirect and induced local economic effects (the “ripple” effects) are not considered.
- Only readily available and published information is used to estimate economic losses from a failure of the embankment or a levee on a neighboring island (no field surveys were conducted). Where necessary, professional judgment is used to supplement available information to estimate economic losses.

Following the general USBR guidelines for risk analysis, risk may be defined as the product of the probability of a loading event, times the probability of system failure when subjected to the loading event, times the consequences of system failure.

An "event tree" model was used to represent the chronological sequence of events from the occurrence of a loading event to the embankment failure to consequences of failure. Figure 1 shows a schematic representation of the event tree model that was used to analyze the risk of embankment failure. This model was applied to each of the two reservoir islands – Webb Tract and Bacon Island. The main steps in implementing the model for each reservoir island were as follows:

- Identify alternative projects for the project embankment.
- Identify loading events.
- Characterize alternative load levels of each loading event.
- Characterize alternative operational scenarios.
- Evaluate the probability of a breach for each combination of loading event, load level, and operational scenario.
- Evaluate probabilities of alternative breach scenarios given the occurrence of a breach.
- Evaluate the expected consequences of each breach scenario.
- Integrate the information from the previous steps to calculate the risk of failure.

A brief description of each step follows.

2.1.1 Identify Alternative Projects for the Reservoir Island Embankments.

The set of alternative engineered projects included the "no-action" alternative (i.e., the existing levee), the re-engineered project as currently defined, and any project variations that were identified based on the engineering evaluations conducted in the other task orders in this study.

2.1.2 Identify Loading Events.

Three types of loading events were analyzed to evaluate the risk of embankment failure – flooding, seismic, and operational.

2.1.3 Characterize Alternative Load Levels of Each Loading Event.

The load levels for flooding and seismic events were defined in terms of intervals of the return period. For each interval of the return period, a representative return period was defined for use in the subsequent steps. For operational loading events, only a single load level (corresponding to the critical condition expected to occur each year) was defined. Table 1 shows the different load levels for flooding, seismic, and operational events, the intervals of the return period for each load level, and the representative return period for each interval.

2.1.4 Characterize Alternative Operational Scenarios.

The reservoirs would operate at various levels during a typical year. For risk analysis, two critical stages of the reservoir levels were considered – reservoir full (elevation +4') and reservoir empty (elevation –15'). The reservoir was assumed to be full during the months of April through June and empty during July through March. For a failure due to operational loading, the period of July through March was further sub-divided into two intervals corresponding to the winter and summer/fall months because the water quality impact of a reservoir breach during these two intervals would be different. During the winter months of December through March, the Delta system would receive high flows of fresh water thus mitigating the impact of increased salinity caused by an inward breach of the reservoir. During the months of July through November, the flow of fresh water would be low, which may cause migration of salinity into the Delta if an inward breach were to occur.

The slough water levels vary during daily tide cycles. Each reservoir level was combined with a daily tide cycle that would produce a critical condition. The full reservoir level was combined with a low tide cycle (slough water level at elevation -1') and empty reservoir level was combined with a high tide cycle (slough water level at elevation +3.5').

During a flooding event, which is likely to occur only during the winter months of December through March, the reservoir would be empty (elevation –15') and the slough water level would be high.

Table 2 defines the alternative operational scenarios for each loading event in terms of the reservoir level, the months of annual operation in each level, and the assumed slough water level.

2.1.5 Evaluate the Probability of a Breach given Loading Event, Load Level, and Operational Scenario.

For each combination of the loading event, load level, and operational event, the probability of a breach (leading to an uncontrolled release of water) was evaluated for each of the two project alternatives – Rock Berm and Bench, and for the existing levee. The results of prior studies and engineering judgment were used to evaluate the breach probabilities. The failure modes included overtopping and piping/internal erosion due to flooding, slope instability and liquefaction due to a seismic event, and slope failure and piping/internal erosion under operational loading.

Probabilities of a breach due to seismic events and operational loading were adopted from other URS reports (URS, 2003a; URS, 2003b). The probability of overtopping due to flooding was estimated based on the expected flood level for a given flood event and the wave height. The analysis of flood levels and wave heights is described in the URS flooding analysis report (URS, 2003c). The combined water elevation from the flood level and wave height was compared to the crest elevation to assess whether overtopping would occur. For Webb Tract, the maximum flood levels for 50-, 100-, and 300-year flood events were estimated to be 6.8, 7.1, and 7.2 feet, respectively, and the wind wave runup plus setup for the re-engineered embankment was estimated to range from 0.6 to 1.8 feet. For Bacon Island, the maximum flood level was estimated to be 6.9, 7.3, and 7.5 feet for the 50-, 100-, and 300– year flood events, respectively, and the wind wave runup plus setup for the re-engineered embankment was estimated to range from 0.6 to 1.4 feet. The maximum crest elevation for the re-engineered embankments is 10.3 feet (URS, 2003c).

Based on these data, the probability of overtopping was estimated for the intervals of flood return periods shown in Table 1. The probability was estimated to be 0 for 1- to 10-year and 10- to 150-year flood events. For a 150- to 450-year flood event, the probability of overtopping would range from 0 for up to 300-year flood events to 100% for a 300+ year flood event. For this analysis, an average value of 50% was used for the interval of 150- to 450-year flood event. The probability of overtopping would be 100% for 450-year plus flood events.

The probability of piping/internal erosion failure due to flooding was estimated using the information in a URS report (URS, 2003b). For a 1- to 10-year flood event, the probability of piping/internal erosion was included in the operational loading. This probability was estimated to be about 0.014% for an inward breach and about 0.003% for an outward breach. For a 10 to 150-year flood event, the probability of piping/internal erosion was estimated to be 0.0013%. For a 150- to 450-year flood event, the probability of piping/internal erosion was estimated to 0.0035%. The probabilities of overtopping and piping/internal erosion under each flood event were combined to obtain the total probability of failure for that event. The data were similar for both reservoir islands and the same failure probabilities were assumed for both islands.

For the existing levees at Webb Tract and Bacon Island, the wind wave runup plus setup was assessed to be about 2 feet. The crest of the existing levee was assumed to be at elevation 8', on average, based on topographic maps (URS, 2003b). In this case, the probability of overtopping was assessed to be 0 for up to 10-year flood events. For 10- to 150-year flood events, the probability of overtopping would range from 0 to 100%; for this analysis, an average value of 50% was used. The incremental probability of piping/internal erosion under 100-year flooding was calculated by assuming the same proportional increase from the annual probability of failure under operational loading as that for an engineered alternative. The probability of overtopping would be 100% for 150-year plus flood events.

2.1.6 Evaluate Probabilities of Alternative Breach Scenarios given the Occurrence of a Breach.

For flooding and seismic events, two breach scenarios were analyzed – one breach occurring or two breaches occurring simultaneously. As stated in Section 1.2, the probability of more than two breaches occurring simultaneously under seismic and flooding events was considered to be negligible. The (conditional) probabilities of alternative breach scenarios given the occurrence of at least one breach were estimated using historic data and engineering judgment. Historically, levee failures during flooding have occurred, but more than one breach on a given island have not been observed. Therefore, the occurrence of two breaches of a levee in a single event was judged to be unlikely, particularly for low load levels.

For up to 450-year flood events, the probability of two breaches was considered to be unlikely. For these events, the (conditional) probability of a single breach was estimated to be 100% and the probability of two breaches was assumed to be zero. For a 1,000-year plus flood event, the two breach scenarios were considered to be equally likely and a probability of 50% was assigned to each scenario. For a 450- to 1,000-year flood event, the single-breach scenario was considered to be three times more likely than the two-breach scenario. Therefore, probabilities of 75% and 25% were assigned to the single- and double-breach scenarios, respectively.

Similar rationale was used to estimate the probabilities of breach scenarios under seismic loading. For moderate seismic loading (return period less than 10 years), the probability of two breaches was considered to be small (about 5%). On the other hand, for a seismic event with a return period of 2,500 years, the events of one breach and two breaches were considered to be about equally likely. For intermediate seismic events, the probability of two breaches was adjusted between the boundaries.

Under operational loading, only the single-breach scenario was analyzed. To model the spatial distribution of system failure, each project embankment was divided into individual reaches. Each reach was the section of the project embankment that adjoins a neighboring island such that a failure of the reach would directly impact the neighboring island. The probability of a breach on each reach was estimated based on the proportion of the embankment perimeter assessed for each reach. For example, the reach of the Webb Tract embankment in front of the Bradford Island was estimated to be 15% of the total perimeter of the embankment. Therefore, a probability of 15% was assigned to the breach scenario for this reach. A representative location was assumed for an embankment breach within each reach.

If the breach is outward, the levee on the island adjoining the breach may also fail. The probability of failure of the levee depends on the width of the slough separating the two islands and on the success of any flood fighting measures that may be undertaken. The greater the width of the slough separating the two islands, the less severe would be the threat to the integrity of the neighboring island levee and the probability of a levee breach at the neighboring island would be less. Three categories of slough width were considered – narrow (less than or equal to 1,000 feet), medium (1,000 feet to 2,000 feet) and wide (greater than 2,000 feet). For a wide slough, the probability of a levee failure caused by a breach of the reservoir island was considered to be very small and a 5% probability was assigned to this event. For a wide slough, a longer warning period would be available to deploy flood-fighting measures on the neighboring island. For this case, the probability of successful flood fighting was assessed to be 50%. Probabilities for other slough widths were assessed similarly.

2.1.7 Evaluate the Expected Consequences of Each Breach Scenario.

The economic losses resulting from an inward and outward breach of the project embankment and the flooding of neighboring islands were evaluated. Only the direct economic losses were evaluated; no indirect losses (“ripple effects”) were considered. The various consequences of concern are evaluated in Section 3.

2.1.8 Integrate the Information from the Previous Steps.

This step involves integrating the estimated probabilities and consequences of failure from the previous steps to generate the risk profile of the engineered project. The risk was expressed in terms of the expected life dollar losses during an assumed project life of 50 years.

3.1 CONSEQUENCES OF INWARD BREACH OF PROJECT EMBANKMENT

The economic losses associated with the following consequences of the inward breach of the project embankment were evaluated. The dollar values associated with these economic losses are summarized in Table 3.

3.1.1 Embankment Repair

The nature and extent of the potential damage to the embankment was assessed under each breach scenario and the cost to repair the embankment and restore its functionality was estimated. These costs were estimated for both project alternatives – Rock Berm and Bench.

3.1.2 Damage to Equipment

The damage to the interceptor wells and integrated facilities was assessed under each breach scenario and the cost to repair the damage and restore functionality was estimated. Failure of the interceptor wells without a breach (i.e., due to malfunctioning) was not analyzed. This is because the embankment would have many interceptor wells and several interceptor wells must fail before a significant increase in the groundwater table at a neighboring island would occur thereby causing crop losses. The probability of simultaneous failure of multiple wells due to malfunctioning was judged to be negligible.

3.1.3 Impact to Fish

Fish may be trapped inside the reservoir once the breach is repaired. The cost of seining the fish and transporting them back into the slough was estimated.

3.1.4 Impact to Water Quality and Water Supply

The flow of the Delta water into the reservoir would draw the marine water upstream and could increase the salinity of the Delta water at the pumping stations for Contra Costa Water District (CCWD) and also possibly for the State Water Project (SWP) and Central Valley Project (CVP). This scenario of increased salinity at the pumping stations is analyzed only during the season of low fresh water flows (July through November). During the high fresh water flows (December through March), the increased salinity zone is unlikely to reach the pumping stations.

Because the water treatment equipment is not designed to process high-salinity water, the Delta water at the affected intakes may not be pumped during the period of high salinity. The duration of pumping interruption was assumed to be four days based on discussion with CCWD and the experience with the 1972 Brannan Island failure that caused elevated concentrations of chlorides at Rock Slough. The corresponding loss of water supply would have to be made up from emergency sources. The various water user agencies that depend on the Delta water supply have emergency water storage facilities that could be used in case of a failure of the Delta water supply system. After the normal operating conditions are restored, the water taken out of the emergency source would have to be replenished. The cost of acquiring and pumping the make-up water was estimated under this scenario.

We estimated that CCWD would have to use about 25,000 acre-feet of water from the emergency storage in the Los Vaqueros Reservoir during the period of high salinity. Interruption of water supply would also occur for the SWP and CVP users. Using available data for the SWP and CVP pumping operations and assuming four days of interruption, the volume of water that would be lost to SWP and CVP during an inward breach was estimated to be 50,000 acre-feet. Thus, the total volume of water that would have to be made up following an inward breach during the period of low fresh water flows would be 75,000 acre-feet. Based on our understanding of CCWD operation plans in case of an interruption of Delta water supply, we estimated the cost of acquiring and pumping the make-up water to be $70/acre-feet.

As stated in Sections 1.2 and 2.1.4, the impact to water quality was analyzed only when the breach would be caused under operational loading and there was low fresh water flow. If the embankment were to fail under a seismic or flooding event, many of the existing levees, which are more vulnerable, are also likely to fail under the same event. This scenario would cause system-wide hydraulic changes in the Delta. Although the impact to water quality of such a scenario could be substantial, the incremental impact due to the reservoir breach alone would be relatively small. An additional factor when analyzing a breach under a flooding event is that there would be a large amount of fresh floodwater that would push the zone of salinity-impacted area downstream.

3.1.5 Flooding of Project Island from a Breach of Existing Levee

This scenario addresses the probability and consequences of failure of the candidate project islands under the ”no action” (i.e., existing levee) condition. In this scenario, Webb Tract and Bacon Island are assumed to be operated as farming islands.

A breach of the existing levee on a project island (i.e., Webb Tract or Bacon Island) would flood the island and impact the current resources and infrastructure. The economic losses from these impacts were estimated. Section 3.3 describes the categories of resources that would be impacted and the data and assumptions used to estimate the economic losses. Table 6 in that section summarizes the estimated economic losses for the two project islands (and also for the neighboring islands). The current resources on the project island (crops and infrastructure) would be lost if either the island is converted to a reservoir or the existing levee fails and the island is flooded. For the IDS project, the costs of these impacts would logically be a part of the total project cost and would not be related to the risk of failure of the project embankment. To provide a proper comparison between the estimated risks of the re-engineered project and existing levees, the consequences of flooding the project island were excluded for all alternatives.

The risk of loss of life due to flooding was considered to be insignificant because of limited exposure and sufficient warning time. There is little permanent population inside the two project islands. Individuals involved in such activities as farming would spend only a limited time on the island. Additionally, there should be sufficient warning time to these individuals following a breach and an opportunity to move to higher ground.

3.2 CONSEQUENCES OF OUTWARD BREACH OF PROJECT EMBANKMENT

3.2.1 Embankment Repair

The nature and extent of the potential damage to the embankment was assessed under each breach scenario and the cost to repair the embankment and restore its functionality was estimated. Separate repair costs were estimated for the two project alternatives – Rock Berm and Bench. For the Rock Berm alternative at Webb Tract, the total quantity of new material was estimated to be 5.3 million cubic yards (URS, 2003d). The perimeter of the embankment at Webb Tract was estimated to be 68,247 feet. Therefore, the quantity of new material per foot of the embankment perimeter is approximately 78 cubic yards. The quantity of material per foot of the existing levee was estimated at about 30 cubic yards. Based on cost estimates (URS, 2003d), the unit cost of breach repair was estimated to be $25 per cubic yard for the new embankment and $15 per cubic yard for the existing levee (consisting of earthfill from borrow sources within the reservoir islands). The unit cost of breach repair per foot was calculated to be (78 cubic yards/ft x $25/cubic yard + 30 cubic yards x $15/cubic yard =) $2,400/lineal foot. The width of a breach was assumed to be 1,000 feet. The cost of breach repair at Webb Tract was, therefore, calculated to about $2.4 million. An additional cost of $0.5 million was assumed for foundation repair. The total breach repair cost for the Rock Berm alternative was then estimated at $2.9 million. A similar calculation was made for the Bench alternative at Webb Tract and the resulting breach repair cost was estimated at $4 million. For each alternative, the same breach repair cost was assumed for both reservoir islands.

3.2.2 Damage to Equipment

The probabilities of damaging the interceptor wells and integrated facilities were assessed under each breach scenario and the cost to repair the damage and restore functionality was estimated.

The interceptor wells were assumed to be placed on the embankment at a spacing of 200 feet. For an assumed breach width of 1,000 feet, five interceptor wells would be impacted. Each impacted well would have to be replaced. The construction cost of a well was estimated to be $30,000 (URS, 2003d). Allowing for a contingency for an emergency replacement, the cost of replacing each well was assumed to be $40,000 in this analysis.

Two integrated facilities were assumed for each reservoir island and each facility was assumed to be 1,000 feet wide. If the mid-point of a breach were to be within 500 feet from either end of the integrated facility, it was assumed that the integrated facility would be impacted. Thus, if a breach were to occur such that its mid-point is over a distance of 2,000 feet centered on the integrated facility, the facility would be impacted. The probability of a breach over a distance of 2,000 feet was calculated as (2,000/perimeter of the island). For two integrated facilities, this probability is equal to (2,000 + 2,000)/perimeter. Because the integrated facility would be founded on piles, there is an even chance that it would withstand the impact of an embankment breach without significant damage. That is, the probability of significant damage to the integrated facility when subjected to an embankment breach would be 50%. The probability of significant damage to an integrated facility then would be (4,000/perimeter) x 0.5. Thus, for example, the probability of significant damage to an integrated facility at the Webb Tract is (4,000/68,247) x 0.5 = 0.029. The construction cost of an integrated facility was estimated to be about $50 million (URS/CH2M Hill, 2003). The cost of repairing such a facility for both Rock

Berm and Bench alternatives was estimated to be 1% of the construction cost, 0.01 x $50 million = $500,000. These repair costs were also used for Bacon Island for the Rock Berm and Bench alternatives.

3.2.3 Impact to Fish

An outward breach may damage the fish habitat in the slough. A response to damaged fish habitat may involve repairing the habitat or enhancing an off-site area associated with a natural functioning Delta system. The cost of the response action was assumed to be comparable to costs for an approved habitat restoration plan in the CALFED Ecosystem Restoration Program (CALFED, 2003). An equivalent restoration effort to repair a damaged spawning pool in an eastside Delta tributary was estimated to be $500,000. It was the judgment of the biologists on the project team that long-term damage to the fish habitat was unlikely, because the impacted area from an outward breach would be very small relative to the total Delta water channels and the impacted fish population would be expected to recover naturally. The probability that a habitat restoration action would be required was assessed to be relatively small (10%). Therefore, the expected cost of addressing fish impact was calculated to be (0.1 x $500,000=) $50,000.

3.2.4 Loss of Water from the Reservoir

Approximately 35,000 acre-feet of water would be lost from an outward breach of the project embankment. This volume was based on the difference between the reservoir water elevation +4' and the slough water elevation –1' times the area of the reservoir. This water would have to be subsequently pumped back into the reservoir. The cost of acquiring and pumping the make-up water was assumed to be $70 per acre-foot. This cost estimate was assumed to be similar to the cost of pumping make-up water by CCWD, SWP, and CVP users.

3.2.5 Impact to Water Supply

An outward breach may impact the quality of water in the Delta. The peat material in the embankment breach may increase the total organic carbon (TOC) in the water. Because of a concern about potential health impacts of drinking contaminated water, Contra Costa Water District may interrupt the pumping operations from the Delta, disinfect the contaminated water and blend it with water from Los Vaqueros Reservoir. The impact at SWP and CVP pumping intakes was assumed to be minimal. This is because their intakes are some 15 miles away from the potential area of impact from an outward breach and it is unlikely that water quality at those distances would be affected. Making assumptions similar to those for an inward breach, the total volume of water that would have to be made up by CCWD following an outward breach was estimated to be 25,000 acre-feet and the cost of acquiring and pumping the make-up water was assumed to be $70/acre-foot.

3.2.6 Impact to Marinas and Recreational Water Activities

The flood into the slough could cause damage to the facilities and infrastructure at the marinas in the impacted area. The marinas/docking facilities that could be impacted from an outward breach at the various reaches of each project embankment were identified from an aerial photo of the study area. Only those facilities that were within a distance of 3,000 feet along a water pathway from a potential breach location were considered, because facilities beyond this distance would not be expected to be damaged. The names of the impacted facilities were not available from the aerial photo, but marinas on the following islands were identified: Orwood, Holland Tract, and Lower Jones for a breach at Webb Tract; and Twitchell, Brannan/Andrus, and Bouldin for a breach at Bacon Island. The probability that an outward breach would damage each marina was estimated based on the width of the slough separating the reservoir island embankment and the marina. The estimated probabilities were 50%, 10%, and 0%, respectively for narrow (less than 1,000 feet wide), medium (1,000 feet to 2,000 feet wide), and wide (greater than 2,000 feet wide) sloughs. If a marina were to be damaged, the repair cost and loss of revenues was estimated to be $200,000. This cost was estimated based on typical flood damage insurance claims for buildings and structures. The expected cost of damage to the marinas was calculated at each reservoir island by multiplying the probability of a marina being impacted by the cost of damage at the marina and summing the product over all impacted marinas.

3.2.7 Loss of Life

An outward breach may cause water to flow into the slough at high velocities. The velocities would depend on the width of the slough. The breach analysis in URS (2003c) showed velocity distributions for different slough widths. If the failure occurs at a time when there is major boating and fishing activity in the Delta, this could pose a significant hazard to the people in boats and fishermen in the zone of impact. Based on the results of breach analysis and engineering judgment, the zone of impact was assumed to extend half a mile centered on the breach location. The population at risk was estimated within the zone of impact and an empirical fatality rate was applied to estimate the expected number of fatalities.

A 1997 survey of recreation use in the Delta estimated that approximately 200,000 people use the Delta each year (Delta Protection Commission, 1997). There are 700 miles of waterways in the Delta; however, we estimate that most visitor use is concentrated in about half (350 miles) of the Delta waterways based upon the information in the 1997 survey. These concentrated use areas are located in the western portion of the Delta and include all of the waterways surrounding Bacon and Woodward islands.

The outward breach scenario is assumed to be applicable during the period of April through June when the reservoir would be expected to be full. Of the annual 200,000 users of the Delta waterways, the survey information suggested that about 70% of the users would be during May through September and about 76% would be daytime users. Furthermore, 65% of usage is estimated to be during the weekend (Friday through Sunday). Using these numbers and assuming 350 miles of Delta waterways, the average numbers of users was per day per mile were estimated for the period of April through June for four different scenarios – weekend daytime, weekend nighttime, weekday day time, and weekday nighttime. Table 4 summarizes these usage numbers. To illustrate the calculations, consider weekend daytime scenario. The average number of users in this scenario during May through September would be 200,000 x 0.7 x 0.76 x 0.65 = 69,160. The number of days in this scenario is approximately 3/7 x 153 = 66. Then the average number of users in this scenario per day per mile of Delta waterway would 69,160/(66 x 350) = 3. The conditional probability of a breach in this scenario given that a breach does occur is 3/7 x 0.5 = 0.21.

Based on the analysis of wave velocities resulting from a breach of the reservoir island, it was conservatively assumed that people within a distance of about a half mile from the breach location would be vulnerable to the risk of drowning. The fatality rate for people exposed to this risk was assumed to be 10%. This was based on the judgment that most boats within the zone of vulnerability would be able to withstand the impact of waves without capsizing. Also, people fishing on the shoreline would be farther away from the breach location and most would be able to survive the impact of the slower waves reaching the shore.

The expected number of fatalities given an outward breach was calculated based on the expected number of people within the vulnerability zone and the assumed fatality rate. The results are summarized in Table 4. Thus, for example, the expected number of fatalities for the weekend daytime scenario is 0.21 x 3 x 0.1 = 0.063.

For purposes of cost-benefit analysis, government agencies have recommended the use of "value of a statistical life (VSL)". The VSL is the amount of money one would be "willing to pay" (i.e., willing to invest in a safety improvement action) in order to reduce the expected number of fatalities by one. This concept is appropriate to use in justifying a project that is expected to provide safety benefits (i.e., to reduce the expected number of fatalities). By no means should the VSL be misconstrued as the worth of a human life. Based on guidelines provided by the U. S. Department of Transportation and U. S. Environmental Protection Agency, a VSL of $3 million was used in this analysis.

3.3 CONSEQUENCES OF FLOODING OF NEIGHBORING ISLANDS

In the event of an outward breach on the reservoir-island embankment caused by operational loading, the levee on the island adjoining the breach may also fail. Such a failure could occur due to the impact of waves generated from the reservoir island breach. The probability of failure of the levee depends on the width of the slough separating the two islands and on the success of any flood fighting measures that may be undertaken. The greater the width of the slough separating the two islands, the less severe would be the threat to the integrity of the neighboring island levee and lower would be the probability of a levee breach on the neighboring island.

The failure of the levee on a neighboring island would result in flooding of the island. As noted in Section 1.2, the consequences of flooding of a neighboring island would be included in this risk analysis only if an outward breach of the reservoir island was triggered under operational loading, and this breach triggered a failure of the levee on a neighboring island.

The economic losses from various consequences of flooding a neighboring island were estimated using the data sources shown in Table 5. The approach to estimating the various losses are described in the sections below and the dollar values are summarized in Table 6. For the sake of completeness, Table 6 also includes the various losses from flooding the project islands, although, as noted in Section 3.1.5, these losses were not included in the estimated dollar risk.

The risk of loss of life from the flooding of a neighboring island was considered to be insignificant. This is because there should be sufficient warning time to any individuals inside the neighboring island following a breach of the reservoir island and the individuals should be able to evacuate.

3.3.1 Damage to Levee, Buildings, and Infrastructure

The costs of repairing or replacing damaged levees, buildings, and infrastructure facilities were estimated.

The data on existing levees on the candidate project islands was used to roughly estimate the breach repair cost for the levees on the neighboring islands. As indicated in Section 3.2.1, the quantity of existing levee material was estimated at 30 cubic yards per lineal foot, and a unit repair cost of $15 per cubic yard for the levee and foundation repair cost of $0.5 million were assumed. This resulted in a breach repair cost of about $1 million for 1000-foot-long breach. The number of buildings on adjacent islands was estimated by counting the number of structures mapped on the U.S. Geological Survey 7.5 minute quadrangles. These buildings were cross-checked using a recent aerial photo of the study area.

Building replacement cost is estimated at approximately $200 per square foot based upon a review of recent real estate listings in the study area. These listings varied from approximately $150 to $300 per square foot. The available data is for residential and commercial real estate and is likely to overestimate the replacement cost for agricultural buildings. The damage caused by flooding would not require a complete replacement of a building, but would require major repairs. It was assumed that the unit flood damage repair cost would be about half of the replacement cost, or $100 per square foot. The total flood damage repair costs were calculated assuming that the average building size is approximately 2,000 square feet. This assumption is reasonable based upon the types of buildings (primarily residential and small commercial).

The length of road corridors on each of the adjacent islands was estimated based upon the overlap of GIS road centerlines acquired from the Bay Area Regional Database (BARD). This data included all primary, secondary, and unimproved roads included in the U.S. Geological Survey’s 1:100,000 digital line graph GIS data (U.S. Geological Survey, 2002). The number of bridges connecting to adjacent islands was estimated by counting the number of bridged water crossings on the U.S. Geological Survey 7.5 minute quadrangles. These bridges were cross-checked using a recent aerial photo of the study area. The length of railroad corridors on each of the adjacent islands was estimated based upon intersections with railroads documented in the National Transportation Atlas Data (NTAD) acquired from the Bureau of Transportation Statistics (2002).

The unit cost of road or rail replacement was assumed to be $1 million per mile. The replacement cost of a bridge was estimated to be $500,000 and the bridge repair cost was assumed to be about 5% of the replacement cost. Thus, the estimated bridge repair cost was 0.05 x $500,000 = $25,000.

3.3.2 Impact to Agricultural Resources

Economic losses were estimated from the destruction of existing crops and the loss of future farming during the period in which the land could not be used for farming.

Crop acreages were calculated using GIS data developed by the California Department of Conservation’s Farmland Mapping and Monitoring Program (California Department of Conservation, 2002). Farmland maps are updated every other year. Individual crop types are not differentiated in the farmland mapping data. Our totals included all of the polygons (i.e., unit areas) with the following attributes:

- Prime Farmland
- Farmland of Statewide Importance
- Unique Farmland
- Farmland of Local Importance
- Farmland of Local Potential
- Irrigated Farmland
- Non-Irrigated Farmland
- Irrigated Pasture
- Non-Irrigated Grain

The crop area estimates do not include land identified as grazing land, urban and built-up land, other land, or water.

Total estimated losses are based upon the assumption that two crop seasons would be affected (current and subsequent).

Losses would vary depending upon the season of inundation. There is no specific data on crop types in the study area, but it is reasonable to assume that at least 70% of the crops are summer field crops that would be affected by inundation if the breach occurred between March 1 and November 1. The remaining 30% of cropland may consist of orchards, alfalfa, or other perennial crops that would be affected by inundation during the winter months.

The estimated value of the loss would be approximately $640 per acre. This value is based upon the average California field crop values shown in Table 7.

3.3.3 Impact to Natural Habitats

Natural habitat area was estimated using the California Natural Diversity Data Base (CNDDB) GIS data (CDFG, 2002). Estimates of natural habitat for each island are derived from the intersection of all CNDDB polygons and the perimeter of each of the adjacent islands. The overlapping areas of CNDDB polygons were counted only once. An average cost of habitat restoration in the Delta was assumed to be similar to the cost of the approved habitat restoration plan in the CALFED Ecosystem Restoration Program, which is $50,000/acre (CALFED, 2002).

4.1 NOTATION

n_{ij} = annual mean number of events associated with i - th loading event and j - th load level

p_{ik} = annual probability of k - th operational scenario given i - th loading event

b_{ijk} = probability of embankment failure given i - th loading event, j - th load level, and k - th operational scenario

s_{ijkm} = probability of m - th breach scenario given i - th loading event, j - th load level, and k - th operational scenario

c_{ikm} = economic losses of m - th breach scenario given i - th trigger event, and k - th operational scenario

4.2 CALCULATION OF RISK FOR A GIVEN RESERVOIR ISLAND

The annual risk, *r* (i.e., probability-weighted consequences) of a given project alternative for a given reservoir island is given by:

$$r = \sum_{i} \sum_{j} n_{ij} * \sum_{k} p_{ik} * b_{ijk} * \sum_{m} s_{ijkm} * c_{ikm} \quad (1)$$

The total risk, R during a project life of L years, assuming no discounting, is given by:

$$R = L \times r \quad (2)$$

A project life of 50 years was assumed for this analysis.

5.1 ORGANIZATION OF INPUT PARAMETERS

The input parameters for the risk analysis are organized into tables as identified below. Breach probabilities were evaluated for each of the two re-engineered project alternatives (Rock Berm and Bench) and for the "no-action" alternative.

Parameter	Table Showing Parameter Estimates
Annual mean number of events, n_{ij}	Table 8
Probabilities of operational scenarios, p_{ik}	Table 9
Probability of embankment failure, b_{ijk}	Table 10 (Failure probabilities adopted from URS, 2003a,b,c)
Probabilities of breach scenarios, s_{ijkm}	Table 11
Consequences of inward breach	Table 3
Consequences of outward breach	Table 12
Probability of flooding of neighboring island caused by an outward breach on reservoir island embankment	Table 13
Consequences of flooding of neighboring islands	Table 6
Expected loss of life from an outward breach	Table 4
Summary of consequences of breach scenarios, c_{ikm}	Table 14

5.2 COMPARISON OF FAILURE RISKS OF EXISTING LEVEE AND RE-ENGINEERED PROJECT

Table 15 shows a comparison of the failure probabilities and risks under the "no-action" alternative (i.e., existing levee) and the two re-engineered alternatives at Webb Tract and Bacon Island.

In comparing the expected dollar risk under the existing levee to the In-Delta Storage (IDS) Project alternatives, the economic losses from the flooding of the project island were not included. This is appropriate because for the IDS Project, the loss of current resources would not be related to the risk of failure of the project embankment and hence this consequence is logically a part of the project cost. Since the loss of current resources on the project island is not considered for the IDS Project alternative, a consistent risk comparison requires that the loss not be considered for the "no-action" alternative (existing levee) as well. However, for a stand-alone (i.e., non-comparative) evaluation of the risk of the existing levee, this loss may be included. Table 15 shows the expected dollar risk of the existing levee failure under both scenarios; that is, including and excluding the economic losses caused by the impact to current resources on the project island.

The expected dollar loss with flooding under existing conditions is large because multiple levee failures could occur during a period of 50 years under existing conditions. It is assumed that after a levee failure that causes flooding of a project island, the levee would be repaired and the island would be redeveloped to its current land uses. To illustrate the estimation of the economic losses from flooding of a project island under existing conditions, consider Webb Tract. Table 6 shows that the economic losses from flooding of Webb Tract would be about $21 million. Under existing conditions, the annual probability of an inward breach causing flooding of Webb Tract is about 10% (5% from flooding and 5% from operating loading). Thus, over a project life of 50 years, about 5 inward breaches that cause flooding of Webb Tract would be expected. The total expected economic losses from five flooding events at Webb Tract under existing conditions would be about $100 million. This loss from flooding when added to other losses results in the expected dollar risk of $131 million under existing conditions, as shown in Table 15. Similar calculations for Bacon Island result in the expected dollar risk of $177 million under existing conditions as shown in Table 15.

Referring to Table 15, the failure probability for the existing levee is higher than for the re-engineered alternatives by factors of 6 to 8. The expected dollar risk (without considering the loss of current resources on the project island) for the existing levee is higher than for the re-engineered alternatives by factors of 2 to 6.

A comparison of the two re-engineered alternatives shows that the probability of failure is about the same for the two alternatives at both project islands (see Table 15). The expected dollar risk for the Rock Berm alternative is lower by about 30% than for the Bench alternative at both Webb Tract and Bacon Island. The expected number of fatalities for the Rock Berm alternative is lower than for the Bench alternative by a factor of about 2.5 to 3, at both Webb Tract and Bacon Island.

A comparison of the risks for the two candidate project islands shows that the failure probabilities, the expected dollar risks, and expected number of fatalities for each alternative are about the same for both islands (see Table 15).

Table 16 shows the contributions of the three loading events to the overall failure probability and risk for each project alternative at the two candidate project islands. For the two re-engineered alternatives, the operational loading contributes only 1% to 2% to the failure probability and expected dollar risk. This is because the failure probability for the re-engineered alternatives under operational loading is very small. The flooding and seismic loading contributes about 40% and 60%, respectively, to the failure probability and expected dollar risk for the re-engineered alternatives. The probability of failure under flooding is mostly due to overtopping, while the contribution of piping/internal erosion to the probability of failure is minor. With regard to the expected number of fatalities for the re-engineered alternatives, almost all of the contribution is from seismic loading. Flooding does not contribute to the fatality risk, because only an inward breach is possible under flooding and the fatality risk under an inward breach is negligible.

For the existing levees at the candidate project islands, flooding contributes 62% to 74% to the failure probability. This is because of the relative low crest elevation of the existing levees such that a 100-year flood is likely to cause overtopping. For the expected dollar risk for the existing levees, the operational loading has a major contribution, because of the potential water supply interruption from an inward breach of the existing levees.

The estimated risk for each reservoir island may be used in a cost-benefit analysis of the IDS Project. The benefits of the IDS Project include environmental enhancement, water revenues from users, improved water quality, and recreation. An evaluation of these benefits can be found in a DWR report (DWR, 2002). These benefits may be compared to the project cost and the expected consequences of failure analyzed in this report.

Bureau of Transportation Statistics (2002). National Transportation Atlas Data, Shapefile Download Center. Washington, DC 20590. GIS data available at: http://www.bts.gov/gis/download_sites/ntad02/statedownloadform.html

CALFED (2003). http://calfed.ca.gov/Programs/Ecosystem Restoration/Ecosystem Restoration Accomplishments.html. January 2.

California Agricultural Statistics Service (2002). 2001 field crop value by acre available at: http://www.nass.usda.gov/ca/rev/fldcrp/202fldtb.html

California Department of Conservation (2002). Farmland Mapping and Monitoring Program Delta GIS Data. ArcView GIS data available at: http://www.consrv.ca.gov/DLRP/fmmp/.

California Department of Fish and Game (CDFG) (2002). California Natural Diversity Data Base. Natural Heritage Division, Sacramento, CA.

Delta Protection Commission (1997). Sacramento-San Joaquin Delta Recreation Survey Summary Report, September. URL: http://www.delta.ca.gov/recsur.html

Department of Water Resources (2002). CALFED Bay-Delta Program, “In-Delta Storage Program Draft Report on Economic Analysis”. May.

URS (2003a). In-Delta Storage Program Seismic Analysis. Prepared for Department of Water Resources. April.

URS (2003b). In-Delta Storage Program Embankment Design Analysis. Prepared for Department of Water Resources. April.

URS (2003c). In-Delta Storage Program Flooding Analysis. Prepared for Department of Water Resources. April.

URS (2003d). Earthwork Construction Cost Estimates. Prepared for Department of Water Resources. April.

URS/CH2M Hill (2003). In-Delta Storage Program Hydraulic Structure Construction Cost Estimate. May.

U.S. Bureau of Reclamation (1999). “Dam Safety Risk Analysis Methodology”, Version 3.3, September.

U.S. Geological Survey (2002). Bay Area Regional Database (BARD). GIS data for roads downloaded from internet at: http://bard.wr.usgs.gov/. U.S. Geological Survey, Bay Area Digital Map Library.

Tables

Table 1
Load levels for different loading events

Loading Event	Load Level	Interval of Return Period in Years	Representative Return Period in Years
Flooding	1	1 to 10	5
	2	10 to 150	100
	3	150 to 450	300
	4	450 to 1,000	500
	5	> 1,000	1,000
Seismic	1	1 to 10	5
	2	10 to 100	43
	3	100 to 700	475
	4	700 to 1,500	1,000
	5	> 1,500	2,500
Operational	1	1	1

Table 2
Operational scenarios for different loading events

Loading Event	Operational Scenario	Months of Operation in a Year in This Scenario	Comments
Flooding	Slough water level high (elevation +from 6.6' to 8.0), reservoir empty (elevation –15')	Flooding assumed to occur during December through March; the reservoir would be empty during this time period	Potential for an inward breach of the reservoir.
Seismic	Low tide (slough water level -1'), reservoir full (elevation +4')	April through June	Potential for an outward breach of the reservoir.
	High tide (slough water level +3.5'), reservoir empty (elevation –15')	July through March	Potential for an inward breach of the reservoir.
Operational	Low tide (slough water level -1'), reservoir full (elevation +4')	April through June	Potential for an outward breach of the reservoir.
	High tide (slough water level +3.5'), reservoir empty (elevation –15'), Low fresh water flow	July through November	Potential for an inward breach of the reservoir; because of low fresh water flow, greater impact of breach to water quality
	High tide (slough water level +3.5'), reservoir empty (elevation –15'), High fresh water flow	December through March	Potential for an inward breach of the reservoir; because of high fresh water flow, less impact of breach to water quality

Table 3
Consequences of Inward Breach

	Rock Berm Alternative	Bench Alternative	No Action
Cost of Breach Repair ($000)	2,900	4,000	1,000
Unit Cost of Repairing Interceptor Well ($000/well)	40	40	40
Expected Number of Interceptor Wells Impacted by a Breach	5	5	0
Expected Cost of Repairs to Interceptor Wells ($000)	200	200	0
Unit Cost of Repairing Integrated Facility ($000/facility)	500	500	500
Probability of Damage to Integrated Facility	2.9%	2.9%	0.0%
Expected Cost of Repairs to Integrated Facilities ($000)	14.3	14.3	0.0
Total Repair Cost ($000)	**3,114**	**4,214**	**1,000**
Cost of Fish Entrainment Recovery ($000)	**10**		
Volume of Water Loss (acre-foot)	75,000		
Unit Cost of Acquiring and Pumping to Make Up for the Water Supply during Service Interruption ($/acre-foot)	70		
Total Cost of Making Up the Water Supply during Service Interruption, ($000)[1]	**5,250**		
Notes:			
(1) This cost impact is assumed only for an operational failure during July through November.			

Table 4
Expected Loss of Life From Outward Breach

Possible Months for Outward Breach	Time of Week	Time of Day	Proportion of a Year in This Scenario	Average Number of People in Vulnerability Zone	Fatality Rate	Expected # of Fatalities	Value of a Statistical Life, VSL ($000)	Expected Value of Loss of Life ($000)
April through June	Friday-Sunday	Day Time	0.21	3	10%	0.063	3,000	**189**
		Night Time	0.21	1	10%	0.021	3,000	**63**
	Monday-Thursday	Day Time	0.29	1.2	10%	0.0348	3,000	**104.4**
		Night Time	0.29	0.4	10%	0.0116	3,000	**34.8**
		Total				**0.1304**		**391**

Table 5
Data Sources Evaluated to Estimate Potential Loss of Life and Property

Category of Impact	Units	Source(s) of Data
Life	Count	Sacramento-San Joaquin Delta Recreation Survey (Delta Protection Commission 1997)
Crops	Acres	California Department of Conservation, Farmland Mapping and Monitoring Program GIS data
Buildings	Count	U.S.G.S 7.5 minute quadrangles / aerial photos
Natural Habitats	Acres	California Natural Diversity Data Base (CDFG 2002); aerial photos
Railroads	Miles	U.S.G.S 7.5 minute quadrangles/ U.S.G.S. digital line graph 1:100,000 scale GIS data
Roads	Miles	U.S.G.S 7.5 minute quadrangles
Bridges	Count	U.S.G.S 7.5 minute quadrangles / aerial photos
Gas pipelines	Miles	U.S.G.S 7.5 minute quadrangles/ U.S.G.S. digital line graph 1:100,000 scale GIS data
Marinas	Count	Aerial photos; Hal Schell's Delta Map and Guide (August 1995 Edition)

Table 6
Consequences of Flooding of Islands (1 of 9)

Webb Tract									
Island	**Facility / Resource Impacted**	**Inventory Unit**	**Number of Units Impacted**	**Unit Economic Loss ($000 per Inventory Unit)**	**Economic Loss ($000) from Flooding per Resource**	**Total Economic Loss ($000) from Flooding**	**Slough Width, Wide, Medium, or Narrow**	**Probability of Flooding Given Outward Breach of Embank-ment (from Table 10)**	**Expected Economic Losses ($000)**
Webb Tract (5400.24 Acres)	Crops	Acres	5270	0.64	3,373	21,073			**21,073**
	Buildings	Count	4	200	800				
	Natural Habitats	Acres	0	50	0				
	Perimeter (external levee)	Breach	1	1900	1,900				
	Railways	Miles	0	1000	0				
	Roadways	Miles	15	1000	15,000				
	Bridges	Count	0	25	0				
	Gas Pipelines	Miles	0	1142.857143	0				
	Fish Entrainment Recovery	Breach	0	10	0				
Bethel Island (3514.6 Acres)	Crops	Acres	5,510	0.64	3,526	121,711	Wide	3%	**3,043**
	Buildings	Count	500	200	100,000				
	Natural Habitats	Acres	5	50	250				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	16	1,000	16,000				
	Bridges	Count	1	25	25				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				

Table 6
Consequences of Flooding of Islands (2 of 9)

Webb Tract

Island	Facility / Resource Impacted	Inventory Unit	Number of Units Impacted	Unit Economic Loss ($000 per Inventory Unit)	Economic Loss ($000) from Flooding per Resource	Total Economic Loss ($000) from Flooding	Slough Width, Wide, Medium, or Narrow	Probability of Flooding Given Outward Breach of Embank-ment (from Table 10)	Expected Economic Losses ($000)
Bradford Island (2170.4 Acres)	Crops	Acres	4,212	0.64	2,696	11,606	Narrow	45%	**5,223**
	Buildings	Count	35	200	7,000				
	Natural Habitats	Acres	0	50	0				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	0	1,000	0				
	Bridges	Count	0	25	0				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				
Twitchel Island (3627.2 Acres)	Crops	Acres	7,184	0.64	4,598	37,428	Wide	3%	**936**
	Buildings	Count	25	200	5,000				
	Natural Habitats	Acres	281	50	14,070				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	12	1,000	11,800				
	Bridges	Count	2	25	50				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				

Table 6
Consequences of Flooding of Islands (3 of 9)

Webb Tract									
Island	**Facility / Resource Impacted**	**Inventory Unit**	**Number of Units Impacted**	**Unit Economic Loss ($000 per Inventory Unit)**	**Economic Loss ($000) from Flooding per Resource**	**Total Economic Loss ($000) from Flooding**	**Slough Width, Wide, Medium, or Narrow**	**Probability of Flooding Given Outward Breach of Embank-ment (from Table 10)**	**Expected Economic Losses ($000)**
Brannan Island (15263.4 Acres)	Crops	Acres	28,398	0.64	18,174	448,609	Wide	3%	**11,215**
	Buildings	Count	500	200	100,000				
	Natural Habitats	Acres	5,170	50	258,475				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	3	1,000	2,700				
	Roadways	Miles	67	1,000	67,100				
	Bridges	Count	10	25	250				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				
Bouldin Island (5994.3 Acres)	Crops	Acres	11,694	0.64	7,484	345,844	Wide	3%	**8,646**
	Buildings	Count	20	200	4,000				
	Natural Habitats	Acres	6,028	50	301,400				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	31	1,000	31,000				
	Bridges	Count	2	25	50				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				

Table 6
Consequences of Flooding of Islands (4 of 9)

Webb Tract									
Island	**Facility / Resource Impacted**	**Inventory Unit**	**Number of Units Impacted**	**Unit Economic Loss ($000 per Inventory Unit)**	**Economic Loss ($000) from Flooding per Resource**	**Total Economic Loss ($000) from Flooding**	**Slough Width, Wide, Medium, or Narrow**	**Probability of Flooding Given Outward Breach of Embank-ment (from Table 10)**	**Expected Economic Losses ($000)**
Venice Island (3120.6 Acres)	Crops	Acres	5,750	0.64	3,680	178,225	Wide	3%	**4,456**
	Buildings	Count	5	200	1,000				
	Natural Habitats	Acres	3,159	50	157,935				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	14	1,000	13,700				
	Bridges	Count	0	25	0				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				
Mandeville Island (5215.3 Acres)	Crops	Acres	9,846	0.64	6,302	172,137	Narrow	45%	**77,461**
	Buildings	Count	10	200	2,000				
	Natural Habitats	Acres	2,722	50	136,100				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	26	1,000	25,800				
	Bridges	Count	1	25	25				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				

Table 6
Consequences of Flooding of Islands (5 of 9)

Bacon Island

Island	Facility / Resource Impacted	Inventory Unit	Number of Units Impacted	Unit Economic Loss ($000 per Inventory Unit)	Economic Loss ($000) from Flooding per Resource	Total Economic Loss ($000) from Flooding	Slough Width, Wide, Medium, or Narrow	Probability of Flooding Given Outward Breach of Embank-ment (from Table 10)	Expected Economic Losses ($000)
Bacon Island (5452.06 Acres)	Crops	Acres	5250	0.64	3,360	41,310			**41,310**
	Buildings	Count	75	200	15,000				
	Natural Habitats	Acres	0	50	0				
	Perimeter (external levee)	Breach	1	1900	1,900				
	Railways	Miles	0	1000	0				
	Roadways	Miles	21	1000	21,000				
	Bridges	Count	2	25	50				
	Gas Pipelines	Miles	0	1143	0				
	Fish Entrainment Recovery	Breach	0	10	0				
Woodward Island (1833.3 Acres)	Crops	Acres	3,378	0.64	2,162	18,172	Narrow	45%	**8,177**
	Buildings	Count	15	200	3,000				
	Natural Habitats	Acres	42	50	2,100				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	9	1,000	9,000				
	Bridges	Count	0	25	0				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				

Table 6
Consequences of Flooding of Islands (6 of 9)

Bacon Island									
Island	**Facility / Resource Impacted**	**Inventory Unit**	**Number of Units Impacted**	**Unit Economic Loss ($000 per Inventory Unit)**	**Economic Loss ($000) from Flooding per Resource**	**Total Economic Loss ($000) from Flooding**	**Slough Width, Wide, Medium, or Narrow**	**Probability of Flooding Given Outward Breach of Embank-ment (from Table 10)**	**Expected Economic Losses ($000)**
Orwood Island (2310.0 Acres)	Crops	Acres	4,405	0.64	2,819	26,999	Medium	18%	**4,725**
	Buildings	Count	35	200	7,000				
	Natural Habitats	Acres	15	50	745				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	15	1,000	14,500				
	Bridges	Count	1	25	25				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				
Palm Tract (2524.5 Acres)	Crops	Acres	4,798	0.64	3,071	27,746	Narrow	45%	**12,486**
	Buildings	Count	15	200	3,000				
	Natural Habitats	Acres	2	50	115				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	2	1,000	2,400				
	Roadways	Miles	17	1,000	17,200				
	Bridges	Count	2	25	50				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				

Table 6
Consequences of Flooding of Islands (7 of 9)

Bacon Island									
Island	**Facility / Resource Impacted**	**Inventory Unit**	**Number of Units Impacted**	**Unit Economic Loss ($000 per Inventory Unit)**	**Economic Loss ($000) from Flooding per Resource**	**Total Economic Loss ($000) from Flooding**	**Slough Width, Wide, Medium, or Narrow**	**Probability of Flooding Given Outward Breach of Embank-ment (from Table 10)**	**Expected Economic Losses ($000)**
Holland Tract (4225.4 Acres)	Crops	Acres	8,304	0.64	5,315	36,870	Narrow	45%	**16,591**
	Buildings	Count	25	200	5,000				
	Natural Habitats	Acres	4	50	195				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	24	1,000	24,400				
	Bridges	Count	2	25	50				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				
Quimby Island (812.3 Acres)	Crops	Acres	1,481	0.64	948	8,138	Wide	3%	**203**
	Buildings	Count	0	200	0				
	Natural Habitats	Acres	106	50	5,280				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	0	1,000	0				
	Bridges	Count	0	25	0				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				

Table 6
Consequences of Flooding of Islands (8 of 9)

Bacon Island

Island	Facility / Resource Impacted	Inventory Unit	Number of Units Impacted	Unit Economic Loss ($000 per Inventory Unit)	Economic Loss ($000) from Flooding per Resource	Total Economic Loss ($000) from Flooding	Slough Width, Wide, Medium, or Narrow	Probability of Flooding Given Outward Breach of Embank-ment (from Table 10)	Expected Economic Losses ($000)
Mandeville Island (5215.3 Acres)	Crops	Acres	9,846	0.64	6,302	172,137	Narrow	45%	**77,461**
	Buildings	Count	10	200	2,000				
	Natural Habitats	Acres	2,722	50	136,100				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	26	1,000	25,800				
	Bridges	Count	1	25	25				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				
McDonald Island (6068.5 Acres)	Crops	Acres	11,479	0.64	7,346	52,771	Narrow	45%	**23,747**
	Buildings	Count	50	200	10,000				
	Natural Habitats	Acres	10	50	490				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	33	1,000	33,000				
	Bridges	Count	1	25	25				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				

Table 6
Consequences of Flooding of Islands (9 of 9)

Bacon Island									
Island	**Facility / Resource Impacted**	**Inventory Unit**	**Number of Units Impacted**	**Unit Economic Loss ($000 per Inventory Unit)**	**Economic Loss ($000) from Flooding per Resource**	**Total Economic Loss ($000) from Flooding**	**Slough Width, Wide, Medium, or Narrow**	**Probability of Flooding Given Outward Breach of Embank-ment (from Table 10)**	**Expected Economic Losses ($000)**
Lower Jones Tract (5995.3 Acres)	Crops	Acres	11,171	0.64	7,149	28,619	Medium	18%	**5,008**
	Buildings	Count	35	200	7,000				
	Natural Habitats	Acres	140	50	7,010				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	6	1,000	5,500				
	Roadways	Miles	0	1,000	0				
	Bridges	Count	2	25	50				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				
Upper Jones Tract (6097.4 Acres)	Crops	Acres	12,003	0.64	7,682	28,262	Medium	18%	**4,946**
	Buildings	Count	40	200	8,000				
	Natural Habitats	Acres	212	50	10,620				
	Perimeter (external levee)	Breach	1	1,900	1,900				
	Railways	Miles	0	1,000	0				
	Roadways	Miles	0	1,000	0				
	Bridges	Count	2	25	50				
	Gas Pipelines	Miles	0	1,143	0				
	Fish Entrainment Recovery	Breach	1	10	10				

Notes:
(1) Crops: Based upon average field crop value for 2001 of $640 per acre, and 2-crop season.
(2) Buildings: Assumes $100/sq. feet and average size of 2,000 square feet.
(3) Natural Habitats: Based upon an average cost of habitat restoration in the Delta of $50,000.
(4) Gas Pipelines: Based upon $80 million to construct 70 miles of 20-inch pipeline.

Table 7
Value of Selected Field Crops in California in 2001

Crop Type	Yield (tons per acre)	Average Price ($ per ton)	Value per Acre ($)
Corn For Grain	4.8	$89.3	$425.0
Winter Wheat For Grain	2.1	$100.0	$210.0
Hay, Alfalfa	7.0	$120.0	$840.0
Sugar Beets	35.7	$30.4	$1,085.3
Average	12.4	$84.9	$640.1

Source: California Agricultural Statistics Service 2002.

Table 8
Annual Mean Number of Events in Each Load Level

Loading Event, *i*	Load Level, *j*	Interval of Return Period, Years	Annual Mean Number of Events, n_{ij}
Flooding	1	1 to 10	0.9000
	2	10 to 150	0.0933
	3	150 to 450	0.0044
	4	450 to 1000	0.0012
	5	> 1000	0.0010
Seismic	1	1 to 10	0.9000
	2	10 to 100	0.0900
	3	100 to 700	0.0086
	4	700 to 1,500	0.0008
	5	> 1,500	0.0007
Operational	1	1	1.0000

Table 9
Annual Probabilities of Operational Scenarios

Loading Event, *i*	Operational Scenario, *k*	Annual Probability of Operational Scenario, p_{ik}: Re-Engineered Project	Annual Probability of Operational Scenario, p_{ik}: No Action (Existing Levee)
Flooding	1. Slough water level high (elevation +6.6' to 8.0'), reservoir empty (elevation –15')	1	1
Seismic	1. Low tide (slough water level -1'), reservoir full (elevation +4')	0.25	0
	2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	0.75	1
Operational	1. Low tide (slough water level -1'), reservoir full (elevation +4')	0.25	0
	2. High tide (slough water level +3.5'), reservoir empty (elevation –15'), Low fresh water flow	0.42	0.56
	3. High tide (slough water level +3.5'), reservoir empty (elevation –15'), High fresh water flow	0.33	0.44

Table 10
Probability of Embankment Failure

			Webb Tract			Bacon Island		
			Rock Berm Alternative	Bench Alternative	No Action	Rock Berm Alternative	Bench Alternative	No Action
Loading Event, *i*	**Load Level, *j***	**Operational Scenario, *k***	% Probability of Embankment Failure under Engineered Project, b_{ijk}	% Probability of Embankment Failure under Engineered Project, b_{ijk}	% Probability of Embankment Failure under "No Action" Alternative, b'_{ijk}	% Probability of Embankment Failure under Engineered Project, b_{ijk}	% Probability of Embankment Failure under Engineered Project, b_{ijk}	% Probability of Embankment Failure under "No Action" Alternative, b'_{ijk}
Flooding	1. Return period = 1 to 10 years	1. Slough water level high (elevation +6.6'), reservoir empty (elevation –15')	0%	0%	0%	0%	0%	0%
	2. Return period = 10 to 150 years	1. Slough water level high (elevation +7'), reservoir empty (elevation –15')	0.0013%	0.0013%	50.4%	0.0013%	0.0013%	50.17%
	3. Return period = 150 to 450 years	1. Slough water level high (elevation +7.2'), reservoir empty (elevation –15')	50.003%	50.003%	100%	50.003%	50.003%	100%
	4. Return period = 450 to 1,000 years	1. Slough water level high (elevation +7.6'), reservoir empty (elevation –15')	100%	100%	100%	100%	100%	100%
	5. Return period greater than 1,000 years	1. Slough water level high (elevation +8'), reservoir empty (elevation –15')	100%	100%	100%	100%	100%	100%
Seismic	1. Return period = 1 to 10 years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	2. Return period = 10 to 100 years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	0.01%	0.17%	0.00%	0.01%	0.21%	0.00%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	0.13%	0.25%	0.48%	0.11%	0.26%	0.47%
	3. Return period = 100 to 700 years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	1.71%	21.63%	0.00%	1.95%	25.87%	0.00%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	74.86%	74.87%	76%	78.00%	78.01%	79.21%
	4. Return period = 700 to 1,500 years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	40.00%	51.00%	0%	32.50%	58.00%	0.00%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	86.50%	87.00%	88.0%	88.00%	88.50%	90.00%
	5. Return period greater than 1,500 years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	95.00%	95.00%	0.0%	95.00%	95.00%	0.00%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	95.00%	95.00%	95.0%	95.00%	95.00%	95.00%
Operational	Return period = 1 year	1. Low tide (slough water level -1'), reservoir full (elevation +4')	0.0029%	0.0029%	5.0%	0.0029%	0.0029%	2.0%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15'), Low fresh water flow	0.01440%	0.01440%	5.0%	0.01440%	0.01440%	2.0%
		3. High tide (slough water level +3.5'), reservoir empty (elevation –15'), High fresh water flow	0.01440%	0.01440%	5.0%	0.01440%	0.01440%	2.0%

Table 11
Probabilities of Breach Scenarios (1 of 2)

				Webb Tract	Bacon Island	No Action
Loading Event, *i*	**Load Level, *j***	**Operational Scenario, *k***	**Breach Scenario, *m***	**Probability of Breach Scenario, s_{ijkm}**	**Probability of Breach Scenario, s_{ijkm}**	**Probability of Breach Scenario, s_{ijkm}**
Flooding	1. Return period = 1 to 10 years	1. Slough water level high (elevation +6.6'), reservoir empty (elevation –15')	One inward breach	100%	100%	100%
			Two inward breaches	0%	0%	0%
	2. Return period = 10 to 150 years	1. Slough water level high (elevation +7'), reservoir empty (elevation –15')	One inward breach	100%	100%	100%
			Two inward breaches	0%	0%	0%
	3. Return period = 150 to 450 years	1. Slough water level high (elevation +7.2'), reservoir empty (elevation –15')	One inward breach	100%	100%	100%
			Two inward breaches	0%	0%	0%
	4. Return period = 450 to 1,000 years	1. Slough water level high (elevation +7.6'), reservoir empty (elevation –15')	One inward breach	75%	75%	75%
			Two inward breaches	25%	25%	25%
	5. Return period greater than 1,000	1. Slough water level high (elevation +8'), reservoir empty (elevation –15')	One inward breach	50%	50%	50%
			Two inward breaches	50%	50%	50%
Seismic	1. Return period = 1 to 10 years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	One outward breach	95.2%	95.2%	95.2%
			Two outward beaches	4.8%	4.8%	4.8%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	One inward breach	95.2%	95.2%	95.2%
			Two inward breaches	4.8%	4.8%	4.8%
	2. Return period = 10 to 100 years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	One outward breach	90.9%	90.9%	90.9%
			Two outward beaches	9.1%	9.1%	9.1%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	One inward breach	90.9%	90.9%	90.9%
			Two inward breaches	9.1%	9.1%	9.1%
	3. Return period = 100 to 700 years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	One outward breach	76.9%	76.9%	76.9%
			Two outward beaches	23.1%	23.1%	23.1%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	One inward breach	76.9%	76.9%	76.9%
			Two inward breaches	23.1%	23.1%	23.1%
	4. Return period = 700 to 1,500years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	One outward breach	62.5%	62.5%	62.5%
			Two outward beaches	37.5%	37.5%	37.5%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	One inward breach	62.5%	62.5%	62.5%
			Two inward breaches	37.5%	37.5%	37.5%
	5. Return period greater than 1,500 years	1. Low tide (slough water level -1'), reservoir full (elevation +4')	One outward breach	52.6%	52.6%	52.6%
			Two outward beaches	47.4%	47.4%	47.4%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15')	One inward breach	52.6%	52.6%	52.6%
			Two inward breaches	47.4%	47.4%	47.4%

Table 11
Probabilities of Breach Scenarios (2 of 2)

				Webb Tract	Bacon Island	No Action
Loading Event, *i*	Load Level, *j*	Operational Scenario, *k*	Breach Scenario, *m*	Probability of Breach Scenario, s_{ijkm}	Probability of Breach Scenario, s_{ijkm}	Probability of Breach Scenario, s_{ijkm}
Operational - Webb Tract	Return period = 1 year	1. Low tide (slough water level -1'), reservoir full (elevation +4')	Outward breach on reach in front of Bethel Island	0%		0%
			Outward breach on reach in front of Bradford Island	15%		15%
			Outward breach on reach in front of Twitchell Island	12%		12%
			Outward breach on reach in front of Brannan Island	12%		12%
			Outward breach on reach in front of Bouldin Island	6%		6%
			Outward breach on reach in front of Venice Island	6%		6%
			Outward breach on reach in front of Mandeville Island	9%		9%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15'), Low fresh water flow	One inward breach	100%		100%
		3. High tide (slough water level +3.5'), reservoir empty (elevation –15'), High fresh water flow	One inward breach	100%		100%
Operational - Bacon Island	Return period = 1 year	1. Low tide (slough water level -1'), reservoir full (elevation +4')	Outward breach on reach in front of Woodward Island		11%	11%
			Outward breach on reach in front of Orwood Tract		2%	2%
			Outward breach on reach in front of Palm Tract		21%	21%
			Outward breach on reach in front of Holland Tract		17%	17%
			Outward breach on reach in front of Quimby Island		11%	11%
			Outward breach on reach in front of Mandeville Island		17%	17%
			Outward breach on reach in front of McDonald Island		0%	0%
			Outward breach on reach in front of Lower Jones Tract		19%	19%
			Outward breach on reach in front of Upper Jone Tract		2%	2%
		2. High tide (slough water level +3.5'), reservoir empty (elevation –15'), Low fresh water flow	One inward breach		100%	100%
		3. High tide (slough water level +3.5'), reservoir empty (elevation –15'), High fresh water flow	One inward breach		100%	100%

Table 12
Consequences of Outward Breach

	Rock Berm Alternative	Bench Alternative	No Action
Cost of Breach Repair ($000)	2,900	4,000	1,000
Unit Cost of Repairing Interceptor Well ($000/well)	40	40	40
Expected Number of Interceptor Wells Impacted by a Breach	5	5	0
Expected Cost of Repairs to Interceptor Wells ($000)	200	200	0
Unit Cost of Repairing Integrated Facility ($000/facility)	500	500	500
Probability of Damage to Integrated Facility	2.9%	2.9%	0.0%
Expected Cost of Repairs to Integrated Facilities ($000)	14.3	14.3	0.0
Total Repair Cost ($000)	**3,114**	**4,214**	**1,000**
Cost of Mitigation to Fish Impact ($000)		500	
Probability of Requiring Mitigation		10%	
Expected Cost of Mitigation to Fish Impact ($000)		**50**	
Cost of Repairs to Facilities and Boats at Marinas for Webb Tract ($000)		**220**	
Cost of Repairs to Facilities and Boats at Marinas for Bacon Island ($000)		**60**	
Volume of Water Loss (acre-foot) due to pumping service interruption		25,000	
Volume of Water Loss from Reservoir (acre-foot)			
Unit Cost of Acquiring and Pumping to Make Up for the Water Loss ($/acre-foot)		70	
Total Cost of Making Up the Water Supply during Service Interruption, ($000)[2]		**1,750**	

Notes:
(1) Consequences of flooding of neighboring islands caused by an outward breach are shown separately in Table 6.
(2) This cost impact is assumed only for an operational failure during July through November.

Table 13
Probability of Flooding of Neighboring Island Given Outward Breach of Reservoir Island Embankment

Slough Width	Probability Wave Impact Initiates a Breach on Neighboring Island Levee, *a*	Probability that Flood Fighting Measures on Neighboring Island Are Successful, *b*	Probability that Neighboring Island is Flooded due to Outward Breach of Reservoir
Wide	5%	50%	**2.5%**
Medium	25%	30%	**17.5%**
Narrow	50%	10%	**45.0%**

Table 14
Summary of Consequences of Breach Scenarios (1 of 2)

Webb Tract

Loading Event, *i*	Operational Scenario, *k*	Breach Scenario, *m*	Repair Costs - Rock Berm Alternative ($000)	Repair Costs - Bench Alternative ($000)	Repair Costs - No Action ($000)	Cost of Fish Entrainment Recovery ($000)	Cost of Mitigation to Fish Impact ($000)	Cost of Making Up Water Supply ($000)	Cost of Repairs at Marinas ($000)	Expected Cost of Flooding of Islands ($000)	Expected Value of Loss of Life ($000)	Consequences of Given Breach Scenario - Rock Berm Alternative ($000), c_{ikm}	Consequences of Given Breach Scenario - Bench Alternative ($000), c_{ikm}	Consequences of Given Breach Scenario - No Action ($000), c_{ikm}
Flooding	1. Slough water level high (elevation +6.6' to 8'), reservoir empty (elevation –15')	One inward breach	3,114	4,214	1,000	10				21,073		**3,124**	**4,224**	**22,083**
		Two inward breaches	6,229	8,429	2,000	10				21,073		**6,239**	**8,439**	**23,083**
Seismic	1. Low tide (slough water level -1'), reservoir full (elevation +4')	One outward breach	3,114	4,214	1,000		50		220		391	**3,775**	**4,875**	
		Two outward breaches	6,229	8,429	2,000		50		440		782	**7,501**	**9,701**	
	2. High tide (slough water level +3.5'), reservoir empty	One inward breach	3,114	4,214	1,000	10				21,073		**3,124**	**4,224**	**22,083**
		Two inward breaches	6,229	8,429	2,000	10				21,073		**6,239**	**8,439**	**23,083**
Operational	1. Low tide (slough water level -1'), reservoir full (elevation +4')	Outward breach on reach in front of Bethel Island	3,114	4,214	1,000		50	1,750	220	3,043	391	**8,568**	**9,668**	
		Outward breach on reach in front of Bradford Island	3,114	4,214	1,000		50	1,750	220	5,223	391	**10,748**	**11,848**	
		Outward breach on reach in front of Twitchell Island	3,114	4,214	1,000		50	1,750	220	936	391	**6,461**	**7,561**	
		Outward breach on reach in front of Brannan Island	3,114	4,214	1,000		50	1,750	220	11,215	391	**16,741**	**17,841**	
		Outward breach on reach in front of Bouldin Island	3,114	4,214	1,000		50	1,750	220	8,646	391	**14,172**	**15,272**	
		Outward breach on reach in front of Venice Island	3,114	4,214	1,000		50	1,750	220	4,456	391	**9,981**	**11,081**	
		Outward breach on reach in front of Mandeville Island	3,114	4,214	1,000		50	1,750	220	77,461	391	**82,987**	**84,087**	
	2. High tide (slough water level +3.5'), reservoir empty (elevation –15'), Low fresh water flow	One inward breach	3,114	4,214	1,000	10		5,250		21,073		**8,374**	**9,474**	**27,333**
	3. High tide (slough water level +3.5'), reservoir empty (elevation –15'), High fresh water flow	One inward breach	3,114	4,214	1,000	10				21,073		**3,124**	**4,224**	**22,083**

Table 14
Summary of Consequences of Breach Scenarios (2 of 2)

Bacon Island														
Loading Event, *i*	**Operational Scenario, *k***	**Breach Scenario, *m***	**Repair Costs - Rock Berm Alternative ($000)**	**Repair Costs - Bench Alternative ($000)**	**Repair Costs - No Action ($000)**	**Cost of Fish Entrainment Recovery ($000)**	**Cost of Mitigation to Fish Impact ($000)**	**Cost of Making Up Water Supply ($000)**	**Cost of Repairs at Marinas ($000)**	**Expected Cost of Flooding of Islands ($000)**	**Expected Value of Loss of Life ($000)**	**Consequences of Given Breach Scenario - Rock Berm Alternative ($000), c_{ikm}**	**Consequences of Given Breach Scenario - Bench Alternative ($000), c_{ikm}**	**Consequences of Given Breach Scenario - No Action ($000), c_{ikm}**
Flooding	1. Slough water level high (elevation +6.6' to 8'), reservoir empty (elevation –15')	One inward breach	3,114	4,214	1,000	10				41,310		**3,124**	**4,224**	**42,320**
		Two inward breaches	6,229	8,429	2,000	10				41,310		**6,239**	**8,439**	**43,320**
Seismic	1. Low tide (slough water level -1'), reservoir full (elevation +4')	One outward breach	3,114	4,214	1,000		50		60		391	**3,615**	**4,715**	
		Two outward breaches	6,229	8,429	2,000		50		120		782	**7,181**	**9,381**	
	2. High tide (slough water level +3.5'), reservoir empty	One inward breach	3,114	4,214	1,000	10				41,310		**3,124**	**4,224**	**42,320**
		Two inward breaches	6,229	8,429	2,000	10				41,310		**6,239**	**8,439**	**43,320**
Operational	1. Low tide (slough water level -1'), reservoir full (elevation +4')	Outward breach on reach in front of Woodward Island	3,114	4,214	1,000		50	1,750	60	8,177	391	**13,543**	**14,643**	
		Outward breach on reach in front of Orwood Tract	3,114	4,214	1,000		50	1,750	60	4,725	391	**10,090**	**11,190**	
		Outward breach on reach in front of Palm Tract	3,114	4,214	1,000		50	1,750	60	12,486	391	**17,851**	**18,951**	
		Outward breach on reach in front of Holland Tract	3,114	4,214	1,000		50	1,750	60	16,591	391	**21,957**	**23,057**	
		Outward breach on reach in front of Quimby Island	3,114	4,214	1,000		50	1,750	60	203	391	**5,569**	**6,669**	
		Outward breach on reach in front of Mandeville Island	3,114	4,214	1,000		50	1,750	60	77,461	391	**82,827**	**83,927**	
		Outward breach on reach in front of McDonald Island	3,114	4,214	1,000		50	1,750	60	23,747	391	**29,113**	**30,213**	
		Outward breach on reach in front of Lower Jones Tract	3,114	4,214	1,000		50	1,750	60	5,008	391	**10,374**	**11,474**	
		Outward breach on reach in front of Upper Jones Tract	3,114	4,214	1,000		50	1,750	60	4,946	391	**10,311**	**11,411**	
	2. High tide (slough water level +3.5'), reservoir empty (elevation –15'), Low fresh water flow	One inward breach	3,114	4,214	1,000	10		5,250		41,310		**8,374**	**9,474**	**47,570**
	3. High tide (slough water level +3.5'), reservoir empty (elevation –15'), High fresh water flow	One inward breach	3,114	4,214	1,000	10				41,310		**3,124**	**4,224**	**42,320**

Table 15
Comparison of Risks under Re-Engineered Project Alternatives and Existing Levees

Reservoir Island	Annual Failure Probability			Expected Dollar Risk during 50 Years ($000)			Expected Number of Fatalities during 50 Years		
	Rock Berm	Bench	Existing Levee	Rock Berm	Bench	Existing Levee	Rock Berm	Bench	Existing Levee
Webb Tract	0.0213	0.0225	0.1740	2,085	2,972	13,152 w/o flooding losses 131,175 w/ flooding losses	0.0025	0.0064	Insignificant
Bacon Island	0.0217	0.0231	0.1440	2,112	3,059	7,231 w/o flooding losses 176,650 w/ flooding losses	0.0025	0.0073	Insignificant

Table 16
Risk Contributions of Loading Events

Reservoir Island	% Contribution to Annual Failure Probability			% Contribution to Expected Dollar Risk during 50 Years ($000)				% Contribution to Expected Number of Fatalities during 50 Years		
	Rock Berm	Bench	Existing Levee	Rock Berm	Bench	Existing Levee w/o Flooding Losses	Existing Levee w/ Flooding Losses	Rock Berm	Bench	Existing Levee
Webb Tract										
-Flooding	42	39	62	39	37	21	45	0	0	
-Seismic	57	60	9	59	61	4	7	99	100	N/A
-Operational	1	1	29	2	2	75	48	1	0	
-Total	100	100	100	100	100	100	100	100	100	
Bacon Island										
-Flooding	41	38	74	39	36	38	64	0	0	
-Seismic	58	61	12	59	62	7	10	98	99	N/A
-Operational	1	1	14	2	2	55	26	2	1	
-Total	100	100	100	100	100	100	100	100	100	

Figures

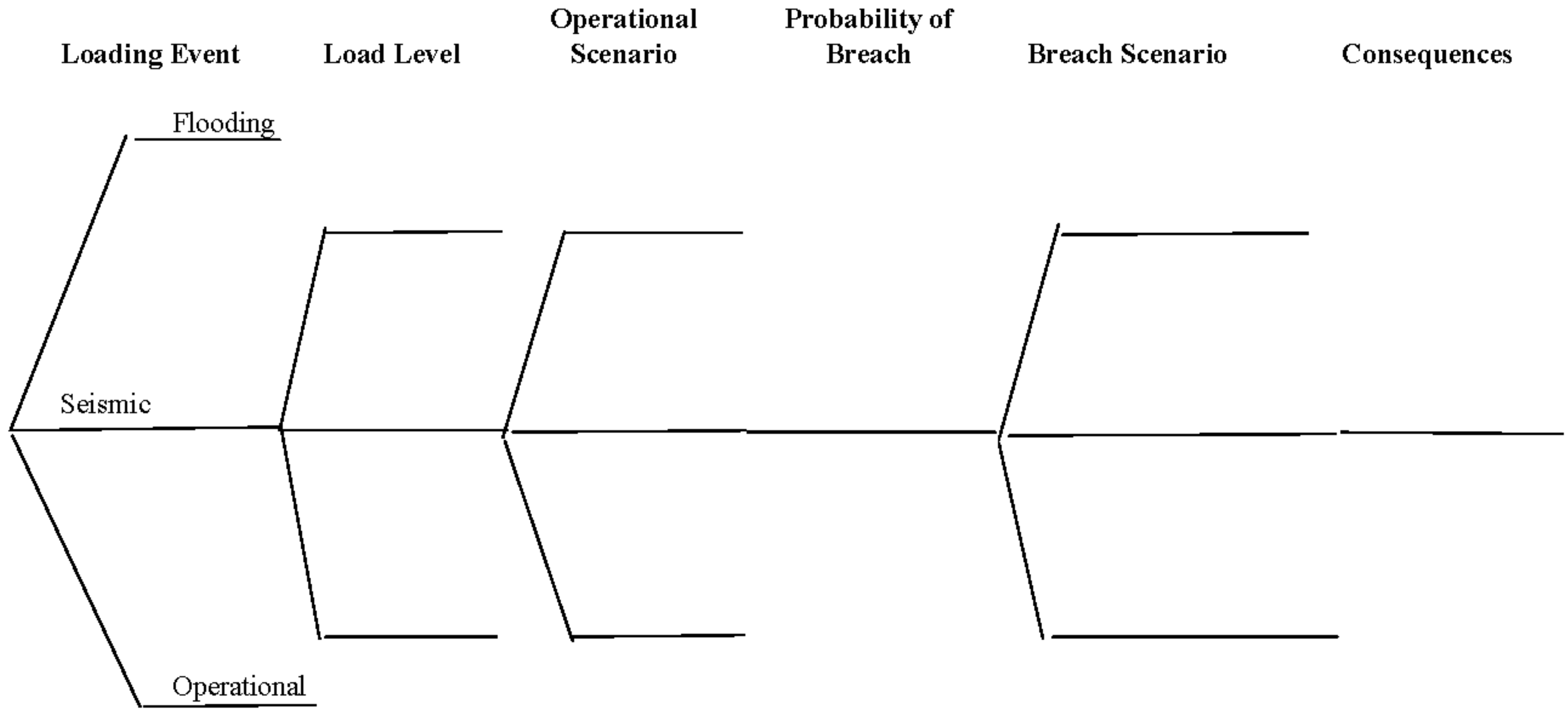

Figure 1 Risk Analysis Model